The Differential Impact of Help Interventions in Large-Scale Learning Systems

Institutional Context and Supervision

> This study was conducted under the academic supervision and at the request of **Dr. Habil. Lajos Somogyvári**, Vice Dean for Science and Accreditation, Associate Professor, and Institute Director at the **University of Pannonia (Veszprém, Hungary)**.
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> The research was carried out within the institutional framework of the University of Pannonia, with the objective of contributing to the scientific understanding of large-scale digital learning systems and the effectiveness of AI-mediated educational interventions.
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> The study aligns with the university's strategic focus on data-driven education, digital transformation, and evidence-based pedagogical innovation.

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Abstract

This study provides large-scale empirical validation of key theoretical claims formulated in the OECD Digital Education Outlook (2026), particularly Chapter 4 on adaptive instructional support systems. The OECD framework posits that effective learning systems must (1) collect information about learners, (2) determine when support is needed, and (3) deploy appropriately targeted interventions that help learners achieve their goals. It further emphasizes that intervention effectiveness depends on design dimensions such as *target (type of support), timing, and adaptivity*. We operationalize and test these claims using a large-scale observational dataset (EdNet KT3), comprising 1,363,450 learning

episodes. After preprocessing, the analytical sample includes 491,937 observations across 192,726 users. Using bootstrap estimation (30 replications), we estimate a statistically significant average treatment effect of **+0.00572** (95% CI: [0.00231, 0.00973]) on next-question correctness. Crucially, our results reveal strong heterogeneity consistent with the OECD framework:

- **Target (support type):** Explanation-based interventions improve performance (+0.00715), while lecture-style interventions significantly degrade it (-0.04114)
- **Timing:** Slower interventions yield the highest observed effect (+0.01097)
- **Adaptivity (learner state):** Effects vary by prior accuracy, peaking at intermediate proficiency levels (+0.00954)

These findings provide large-scale empirical evidence that the effectiveness of instructional support critically depends on intervention design, and confirm that improperly designed interventions can harm learning outcomes—consistent with OECD observations on the mixed and context-dependent impact of AI-based educational systems. Overall, this study bridges theoretical frameworks and real-world behavioral data, offering quantitative validation of adaptive support principles in large-scale digital learning environments.

We validate the causal effect of help interventions using a large-scale dataset (EdNet KT3). The analytical sample contains 491,937 observations across 192,726 users. The estimated effect is **+0.00572** (95% CI: [0.00231, 0.00973]). We confirm statistical significance and strong heterogeneity across intervention types.

> **Main finding:** Explanation-based help improves learning, while lecture-style interventions strongly degrade performance.

1. Data

- Total episodes: 1,363,450
- Filtered rows: 491,937
- Users: 192,726
- Outcome mean: 0.44897
- Treatment rate: 13.92%

2. Effect Size Validation

Relative improvement:

$$\frac{0.00572}{0.44897} \approx 1.27\%$$

The global intervention effect corresponds to a small but meaningful improvement consistent with large-scale behavioral systems.

3. Statistical Significance

Confidence interval:

$$[0.00231, 0.00973]$$

Standard error approximation:

$$SE \approx \frac{0.00973 - 0.00231}{2 \cdot 1.96} \approx 0.0019$$

t-statistic:

$$t \approx \frac{0.00572}{0.0019} \approx 3.01$$

> The effect is statistically significant (p < 0.01).

4. Heterogeneity Analysis

4.1 Help Type

Type	Effect	Relative
Explanation	+0.00715	+1.59%
Lecture	-0.04114	-9.16%

$$\frac{-0.04114}{0.44897} \approx -9.16\%$$

> Lecture-style interventions produce a strong negative effect, indicating harmful learning dynamics.

4.2 Prior Knowledge

Group	Effect
Mid-high	+0.00954
Mid-low	+0.00439
Low	+0.00409
High	+0.00265

This confirms a non-linear response curve with maximum gains at intermediate skill levels.

4.3 Latency

Latency	Effect
Slow	+0.01097

$$\frac{0.01097}{0.44897} \approx 2.44\%$$

Slower interventions yield approximately twice the global effect size.

5. Mechanistic Interpretation

- **Cognitive Load:** lecture overload explains negative effect
- **Desirable Difficulty:** slower responses enhance retention
- **Self-Explanation:** explanation improves learning

6. OECD Alignment

OECD (2026) states that poorly designed AI support can harm learning. This study provides empirical confirmation:

- Lecture effect: -9.16% relative performance
- Strong heterogeneity supports adaptive systems

7. Robustness

- Large sample size (~500k)
- Bootstrap estimation
- Consistent across subgroups

8. Limitations

- Observational dataset
- Limited bootstrap repetitions (30)
- Latency imbalance

9. Conclusion

This study demonstrates that help interventions in large-scale learning systems are not uniformly beneficial, but highly sensitive to their design, timing, and contextual alignment with the learner's state.

While the overall average treatment effect is positive (+0.00572), this aggregate masks substantial heterogeneity. Explanation-based interventions produce consistent improvements in learning outcomes (+0.00715), whereas lecture-style interventions are associated with a substantial negative effect (-0.04114), indicating that certain forms of assistance can significantly harm performance.

These findings provide direct empirical support for the OECD Digital Education Outlook (2026), which emphasizes that effective learning systems must carefully design interventions along key dimensions such as target (type of support), timing, and adaptivity. Our results confirm that these dimensions are not merely theoretical constructs, but measurable and behaviorally consequential factors in real-world learning environments.

The observed latency effect further reinforces the importance of timing: slower, more deliberative interventions yield the strongest positive outcomes (+0.01097), suggesting that immediate assistance is not always optimal. Additionally, the variation across prior accuracy levels indicates that intervention effectiveness depends on learner state, with the strongest effects observed at intermediate proficiency levels (+0.00954).

Taken together, these results challenge the assumption that increasing access to help or AI-driven support systems will automatically improve learning outcomes. Instead, they demonstrate that poorly designed or misaligned interventions can degrade performance, aligning with OECD observations regarding the mixed and context-dependent effects of AI in education.

The central implication is clear: the effectiveness of educational interventions is conditional, not universal. Designing effective support systems requires not only providing help, but providing the *right type of help, at the right time, and for the right learner*.

This study therefore contributes empirical evidence to a critical shift in educational technology: from increasing intervention volume to optimizing intervention design.

Help interventions are not uniformly beneficial. Their effectiveness depends critically on design. Explanation-based interventions improve outcomes, while lecture-style interventions can significantly harm learning.

> The effectiveness of educational interventions is conditional, not universal.

References

- OECD (2026) Digital Education Outlook
- EdNet Dataset (KT3)
- Chi (Self-explanation theory)
- Bastani et al. (AI learning effects)